SPECIAL ARTICLES.

EFFECT OF THE CONCENTRATION OF THE NUTRIENT SOLUTION UPON WHEAT CULTURES.

THE work here reported was undertaken to determine the concentration of a nutrient solution which is best adapted to the growth of wheat, and further to find out whether or not an increase in concentration alone may accelerate growth aside from changes in the nutrient value of the solution. The nutrient solution used contained calcium sulphate, magnesium phosphate, potassium carbonate, sodium nitrate and ammonium chloride in chemically equivalent amounts. It was made up to concentrations of 10, 70, 150, 745 and 1,545 parts per million, respectively. To each solution 5 parts per million of ferric chloride were added, thus making the concentrations of total salts 15, 75, 155, 750 and 1,550 parts per million. In the two higher concentrations some phosphates and carbonates of calcium and magnesium were precipitated out, but the error thus produced is too small to affect the general results under consideration.

A series of cultures of wheat seedlings was grown for 28 days in these solutions, the latter being changed every day. At the end of the period the plants in the solution of 15 parts per million were the poorest of the lot, being remarkably stunted, as though suffering for want of water. Those in the solution of 75 parts per million were considerably better, while those in the solution of 155 parts per million were unmistakably the best. Those in the solution of 750 parts per million were similar to those in the one of 75 parts, while those in the solution of 1,550 parts per million were again very poor and showed the same stunting of growth as do plants growing in alkali soils.

This experiment was performed six times with different growing conditions, and each time the results were in the same order. The general development was always in the same relative order as the transpiration.[1]

[1] For evidence in regard to the use of transpiration as a criterion here, see a paper about to appear in the *Botanical Gazette*, Livingston, B. E., 'Relation of Transpiration to Growth in Wheat.'

In Table I. are given the number of plants used in each experiment and the relative transpirations for the different cultures of the six experiments, all calculated to a uniform basis of 15 days each. In calculating the relative transpirations, the total transpiration of the culture in the weakest solution is considered as 100.

TABLE I.

Data for Experiments I. to VI.

Exp. No.	No. of Plants.	Relative Transpirations for Period of 15 days in Nutrient Solutions of the Following Concentrations:				
		15 p. p. m.	75 p. p. m.	155 p. p. m.	750 p. p. m.	1,550 p. p. m.
I.	24	100	209.3	330.2	197.6	253.5
II.	36	100	132.6	154.4	134.3	107.3
III.	36	100	134.9	181.3	158 9	81.4
IV.	24	100	151.6	151.6	138.3	120.0
V.	24	100	186.1	157.0	193.0	125 5
VI.	60	100	155 5	157.9	157.9	104.1
Av. for 204 plants.		100	161.6	188.7	163.3	131.9

It will be seen from the table that curves of these transpirations would have maximum points somewhere between 155 and 750 parts per million of total solids in solution. No attempt was made to determine the maximum point more accurately, but by interpolation it is estimated to lie in the vicinity of 300 parts per million of total solids. This may be taken as approximately the concentration best suited to growth under the conditions of these experiments.

Whether the depression noticed in the lower concentrations of the above series is due to a scarcity of one or more of the nutritive elements or to the low concentration of the solution as a whole is considered in the following experiments. In experiment VII. to each of four portions of the solution above described, containing 15 parts per million of total salts, were added 140 parts per million of one of the salts occurring in the original solution, a different salt being used in each case. To a fifth portion was added 140 parts per million of a mixture of all four of these salts in chemically equivalent amounts. Twenty-four plants were grown in each of the five solutions for thirteen days, and their growth was compared with that of a similar culture in the

original solution. Table II. presents the data for this experiment as well as for the two following ones. Relative transpirations on the basis of 100 for the original nutrient solution of 15 parts per million are given. There was a marked increase in the growth of the plants, with the addition of each one of the salts, but none of them produced as good plants as did the combination of all four salts.

In experiment VIII. the same solution of 15 parts per million was increased in concentration by the addition of 60, 140, 735 and 1,535 parts per million of calcium sulphate. Thirty-six seedlings were grown in each solution for thirteen days, comparison being again made with the original solution. The increase in transpiration was also very marked in this case, as is shown by the data in Table II. Here the transpiration figures tend to show a depressing effect in the solution of highest concentration, as in the former case. This experiment was repeated with similar results.

TABLE II.

Data for Experiments VII. to IX.

	Medium.	Relative Transpirations for Period of Experiment.
Experiment VII., 24 plants, 13 days.	Nutrient solution, 15 p. p. m.	100.0
	Do. + 140 p. p. m. $CaSO_4$.	205.5
	Do. + 140 p. p. m. $MgHPO_4$.	143.5
	Do. + 140 p. p. m. K_2CO_3.	224.4
	Do. + 140 p. p. m. $NaNO_3$.	156.2
	Do. + 140 p. p. m. of four above salts, in chem. equiv. amounts.	241.9
Experiment VIII., 36 plants, 13 days.	Nutrient solution, 15 p. p. m.	100.0
	Do. + 60 p. p. m. $CaSO_4$.	117.8
	Do. + 140 p. p. m. $CaSO_4$.	157.7
	Do. + 735 p. p. m. $CaSO_4$.	188 9
	Do. + 1535 p. p. m $CaSO_4$.	155.5
Experiment IX., 60 plants, 15 days.	Nutrient solution, 15 p. p. m.	100.0
	Do. + 60 p. p. m. NaCl.	111.1
	Do. + 140 p. p. m. NaCl.	114.9
	Do. + 735 p. p. m. NaCl.	117.2
	Do. + 1535 p. p. m. NaCl.	95.4

Sodium chloride, which furnishes none of the elements usually classified as plant food materials, was also used to increase the concentration of the original solution. Sixty plants were used in this case, being grown for fifteen days. The treatment was the same as that with calcium sulphate just described, and the results showed the same general effect, although the actual differences between the different cultures were not nearly as great. The last fact is probably due to the toxic effect of the chlorine ion, tending to retard growth and thus partially masking the effect of concentration. The data are given in Table II.

From the experiments thus far described it is evident that there is an optimum physical concentration of the nutrient solution at which water cultures of wheat thrive best, aside from variations in the amounts present of the different nutrient materials. In the solutions of lower concentration the retarding factor for plant growth is not necessarily connected with the low osmotic pressure, for the same acceleration of growth which is observed to accompany an increase in concentration can be obtained by entirely different means. The author has already called attention to the fact that both nutrient solutions and soil extracts are greatly improved for the growth of wheat by addition of small quantities of the practically insoluble bodies, carbon black and ferric hydrate[2] and that the beneficial effect of these bodies is due to their power to absorb toxic substances. Such toxic materials are present in many soils, and physiologically similar ones are given off by the roots of wheat grown in water culture.[3] The addition of these insoluble bodies to a weak nutrient solution can not possibly increase its concentration to any appreciable degree; indeed, such addition is apt to decrease its concentration to some extent owing to phenomena of adsorption. Yet such treatments result in the same sort of acceleration of growth as is obtained with increase in concentration.

Dr. B. E. Livingston, of the bureau of soils, has made possible a quantitative comparison in this regard by furnishing the author with

[2] Breazeale, J. F., 'Effect of Certain Solids upon the Growth of Wheat in Water Cultures,' about to appear in the *Botanical Gazette*.

[3] In this regard see Livingston, B. E., Britton, J. C., and Reid, F. R., 'Studies on the Properties of a Sterile Soil, U. S. Dept. Agric., Bureau of Soils, Bul. No. 28.

unpublished data from experiments which he has recently performed. He finds from an average of six different tests in which ferric hydrate was added to the nutrient solution described above, the latter having a concentration of 75 parts per million, that growth is accelerated by this treatment to an extent equivalent to 26.2 per cent., the growth obtained in the untreated solution being considered as unity for the comparison. The same nutrient solution with carbon black gave 35 per cent. increase in growth on the same basis. The last figure is an average of the results of two experiments.

TABLE III.

Data for Experiment XI.

Solution Used on Sand.	Transpiration for 2 Days.	
	In Grs.	Relative.
Nutrient solution, 15 p. p. m.	44	100
Do. 75 p. p. m.	45	102 3
Do. 155 p. p. m.	65	147.7
Do. 750 p. p. m.	127	288.7
Do. 1,550 p. p. m.	150	340 9
Do. 75 p. p. m. + 305 p. p. m. NaCl.	56	127.3
Do. 75 p p. m. + 305 p. p. m. $CaCl_2$.	60	136.4

TABLE IV.

Data for Experiment XII.

Solution Used on Sand.	Transpiration for 2 Days.	
	In Grs.	Relative.
Nutrient solution, 75 p. p. m.	24	100
Do. 750 p. p. m.	50	208.3
Do. 75 p. p. m. + 675 p. p. m. NaCl.	32	133.3
Do. 75 p. p. m. + 675 p. p. m. $CaSO_4$.	31	129.2
Do. 75 p. p. m. + 675 p. p. m. Na_2HPO_4.	35	145.8

The data of experiments I. to VI. of the present paper (Table I.) show that the average growth in the nutrient solution of 75 parts per million is 161.6, and for the same solution of a concentration of 155 parts per million the average growth is 188.7. On the average, the latter concentration is the optimum for wheat growth as nearly as this can be approximated from the series, so that the acceleration which it is possible to obtain by increase in concentration is 188.7 — 161.6/161.6, or 16.8 per cent. Considering only the four experiments which showed an increase in favor of the stronger of these two concentrations (experiments I., II., III. and VI.), this average is, of course, much higher, being 27 per cent., or very nearly the same as the increase obtained by treating the weaker solution with ferric hydrate, and considerably less than that obtained with carbon. Thus we are confronted with a case where two entirely different treatments bring about the same effect upon the plant. It is practically proved that the insoluble bodies have their effect here by removing from solution the deleterious excretions of the plant roots. The effect of increase in concentration may be explained by one or more of the three following hypotheses: The higher concentration may make the plant more resistant to the poisons; it may actually prevent the excretion of such poisons from the roots; or with higher concentration of salts the poisons themselves may be altered so as to lose their toxic properties. Which of these explanations is correct can not be decided now, but it is at any rate very clear that the acceleration observed has no direct connection with the nutrient value of the medium.

In soil or sand cultures the effect of concentration is known to be very different from that in water cultures; for instance, the concentration best suited to wheat in water culture is about 300 parts per million of nutrient solution, while in sand it lies in the vicinity of 2,500 parts per million. To investigate the question whether the effect of strength of solution in sand is due to physical concentration or to chemical conditions of nutriment, several series of sand cultures were carried out.

Pure quartz sand was placed in paraffined wire baskets of the form described in Bulletin No. 23 of this bureau, and the hardened paraffin at the bottom was punctured with pin holes to allow free drainage. In experiment X. six wheat plants were grown in these baskets for sixteen days, the sand being flooded daily with nutrient solutions of concentrations of 15, 75, 750 and 1,550 parts per million of total salts, respectively, while the excess of solution was allowed to drain out

through the bottom. In this way the plants were kept abundantly supplied with fresh solution. At the end of this period the differences in growth were very marked, there being a gradual increase in growth from those flooded with the weakest to those flooded with the strongest solution, the latter culture being by far the best of the series. This experiment was repeated as experiment XI., and in addition the solution of 75 parts per million was increased in concentration by the addition of 305 parts per million of sodium chloride and also of an equal amount of calcium chloride. The baskets were flooded with the solution daily for 18 days, at the end of which time they were sealed over the top with paper and paraffin to prevent evaporation from the surface of the sand, a small opening being left for the stems. The transpirations were then taken for two days and are given in Table III., together with the relative figures obtained by considering the transpiration of the first culture as 100. The figures are relatively proportional to the size of the plants at this time.

Here the same gradation of growth is apparent in the series of different concentrations of nutrient solution as was observed in experiment XI. Furthermore, addition of either sodium chloride or calcium chloride produces a marked increase in growth. This test was repeated as experiment XII., this time taking as controls the nutrient solution in concentrations of 75 and 750 parts per million and increasing the concentration of separate portions of the weaker of these by addition of 675 parts per million of sodium chloride, of calcium sulphate and of sodium phosphate, respectively. The cultures were treated in the same manner as in experiment XI. until the twenty-seventh day, after which they were sealed and weighed. The transpiration for two days is given in Table IV., together with relative figures obtained in the usual manner.

From the last three experiments it appears that in quartz sand as well as in a free solution the concentration of dissolved salts is a factor in determining plant growth, independently of any changes in the nutrient value of the medium. This may be so in ordinary soils, as well, although of course the problem here is complicated by the presence of undissolved nutrient materials in the soil. Ferric hydrate and carbon black have the same beneficial effect when mixed into many infertile soils as has been described for nutrient solutions, so that it appears that the above-mentioned hypotheses regarding toxic materials may be applied here also.

For many years experiment station workers have been studying the problem of the replacement of potassium by sodium compounds in commercial fertilizers. Marked increases in crop yields have been obtained by the addition of sodium chloride to soils receiving only a small amount of potassium. From the experiments here described it appears that this increase in yield may not at all be directly connected with any change in the nutritive content of the soil.

J. F. Breazeale.

Bureau of Soils,
U. S. Department of Agriculture,
Washington, D. C.

THE CLASSIFICATION OF THE ORDOVICIAN ROCKS OF OHIO AND INDIANA.

A more detailed study of the great mass of strata included in the Cincinnatian series of the Ordovician rocks of Ohio, Indiana and Kentucky makes necessary the classification of these strata into divisions and subdivisions of the series. This service was rendered by Mr. John M. Nickles in his papers on the Geology of Cincinnati[1] and on the Richmond group in Ohio and Indiana.[2]

In the twenty-eighth annual report of the Indiana Geological Survey, published in 1903, the classification proposed by Nickles was adopted without change. Since the publication of this report, however, several changes in the nomenclature have seemed advisable. Some of these are due to the practise, which recently has become more general, of adopting distinct names for formations which formerly were considered approximately identical, whenever a study of their fossil faunas indicates that these formations were deposited in zoolog-

[1] *Journal Cincinnati Soc. Nat. Hist.*, 1902.

[2] *Am. Geol.*, 1903.